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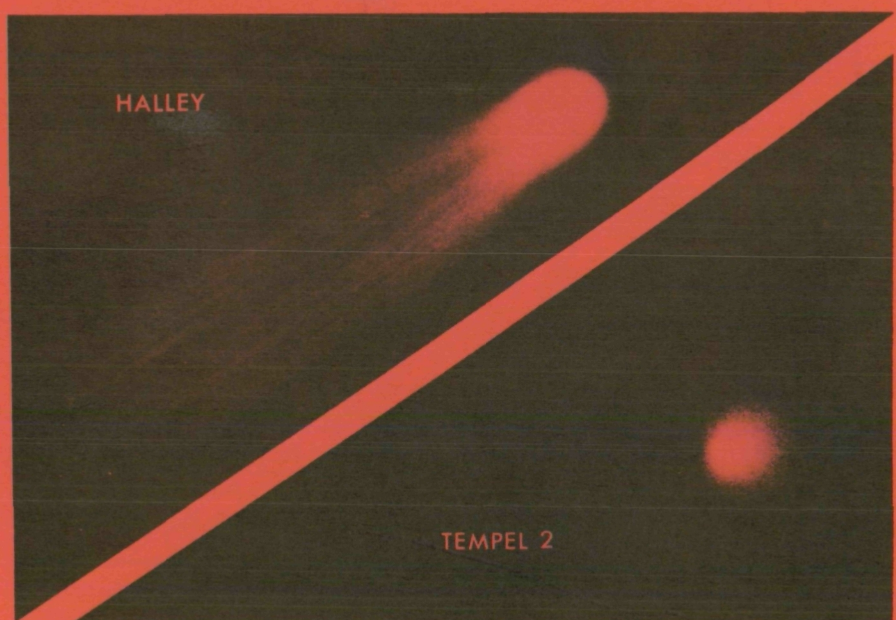
REPORT OF THE COMET SCIENCE WORKING GROUP

EXECUTIVE SUMMARY



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SECTION I

INTRODUCTION

The Comet Science Working Group (CSWG) met four times between October 1978 and April 1979 to consider the scientific objectives, mission strategy, and instrumentation for a first comet mission. Its findings have been published in the Final Report, Volume II of this document, of which this is a summary.

SECTION II

RATIONALE

A major objective of NASA's space program is to deepen our understanding of the origin and evolution of our cosmic environment. The study of comets is an essential element in achieving this goal. Comets are the most pristine, primitive bodies remaining in our solar system. Their study should yield important new data in many diverse fields of research:

(1) Comets may contain a variety of presolar system, interstellar grains, which have so far been unavailable for study.

(2) Comets probably retain evidence of the chemical and physical conditions under which they and the planets formed, especially about the processes of condensation, agglomeration, and mixing that took place.

(3) Comets may have been a major source of the atmospheres of the terrestrial planets.

(4) Comets may have provided the Earth with the organic molecules necessary for the evolution of life.

(5) Comets are a source of meteors and interplanetary dust and possibly of some Apollo/Amor asteroids.

The chemical and physical processes that occur in active comets to produce the spectacular displays observed from Earth are not well understood. In situ studies are needed to clarify these processes and to gain new insights into their connection with other planetary and astrophysical phenomena.

SECTION III

SCIENTIFIC OBJECTIVES

The major scientific objectives of the first space mission to a comet should be, in order of priority:

(1) To determine the chemical nature and physical structure of comet nuclei, and to characterize the changes that occur as functions of time and orbital position.

(2) To characterize the chemical and physical nature of the atmospheres and ionospheres of comets as well as the processes that occur in them, and to characterize the development of the atmospheres and ionospheres as functions of time and orbital position.

(3) To determine the nature of comet tails and the processes by which they are formed, and to characterize the interaction of comets with the solar wind.

This ordering reflects the conviction that the nucleus—the source of all cometary activity, and currently the part of a comet about which we know the least—must be studied in detail. However, the CSWG stresses that the payload selected for the first comet mission should address all three major objectives.

SECTION IV

MISSION MODES AND TARGETS

Types of possible missions, in order of increasing scientific return, are flyby, rendezvous, landing, and sample return. A sample return or landing mission is inappropriate for a first comet mission because our knowledge of comets and their environments is too limited at this stage to plan such a mission, and because many important scientific questions can be addressed by a much simpler rendezvous mission.

To address the major questions, the first mission of a comet program must involve a rendezvous with the nucleus of a comet. By itself, a flyby mission cannot address Objective (1) and some key elements of Objective (2) in any significant way.

The need for a rendezvous mission underscores the need for development of the low-thrust propulsion system required to achieve a cometary rendezvous.

The ideal target for a first cometary mission would be a fresh, bright, well-behaved comet with predictable orbital motion. Halley is the <u>only</u> comet available this century that comes close to this ideal.

The best first comet mission would be a rendezvous with Halley when this comet next passes through the inner solar system in 1985-6. Unfortunately, Halley's retrograde orbit makes a Halley rendezvous mission too difficult to achieve in the time remaining. Of the comets with which a rendezvous can be achieved, Tempel 2 and Encke are the best candidates. However, neither of these smaller and fainter comets shows the full complement of cometary phenomena that Halley is known to possess. While a rendezvous with either Encke or Tempel 2 would be excellent in terms of Objective (1), some aspects of Objectives (2) and (3) would be compromised.

Fortunately, there is a very attractive mission opportunity that allows the study of both an active comet like Halley and a rendezvous with a cometary nucleus. The CSWG strongly recommends that the first comet mission be a flyby of Comet Halley en route to a rendezvous with Comet Tempel 2. Such a mission provides (a) an extended rendezvous phase at Tempel 2 during which Objectives (1) and (2) can be addressed, (b) the opportunity to address Objectives (2) and (3) during the Halley flyby by studying the unique phenomena that occur in the atmosphere of an active comet as a result of its interaction with sunlight and the solar wind, and (c) an opportunity to compare two very different comets. The properties of Comets Halley and Tempel 2 are summarized in Table 4-1.

Tempel 2 is recommended as the rendezvous comet rather than Encke because of technical considerations. The rendezvous with Tempel 2 involves a shorter flight time, a less hostile thermal environment, and a heavier science payload than does a rendezvous with Encke. The potential science return from the two comets is judged to be essentially equal.

SECTION V

MISSION STRATEGY

The times of the major events of the recommended mission are:

July, 1985	Launch
November, 1985	Halley flyby
July, 1988	Rendezvous with Tempel 2
July, 1989	End of mission

Table 4-1. Characteristics of Comets Halley and Tempel 2

Characteristic	Halley	Tempel 2
Observed		
Earliest recorded apparition	87 BC	1873 AD
Number of observed apparitions	27	16
Period	76 years (approximate)	5.3 years
Orbital inclination (with respect to ecliptic)	162 deg	12 deg
Perihelion distance	0.6 AU	1.4 AU
Absolute total magnitude (approximate)	5	10
Photometric behavior	Brighter postperihelion Fountain effect from nucleus sunward Spherical halos expanding from nucleus (0.1 to several km/s) Jets and streamers showing evidence for directed ejection Explosive outbursts Maximum visual coma diameter: $\sim 4 \times 10^5$ km	Rapid brightness increase begins 80 days before perihelion; more gentle brightness decrease postperihelion Sunward fan-shaped coma suggests anisotropic outgassing Maximum visual coma diameter: $\sim 1 \times 10^5$ km
Spectroscopic data	CN, C_2, C_3, CO^+, N_2^+ Strong continuum $^{12}C^{13}C$ isotopic bands in the Swan system of C_2 molecule	CN, C_2, C_3, CO^+ Strong continuum
Tail structure	Dust tail and ion tail present Motion of fine streamers and disconnection phenomena in ion tail	No observed tail; however, the CO^+ emission of the normal onset of an ion tail is observed in the coma region

Table 4-1. Characteristics of Comets Halley and Tempel 2 (Continued)

Characteristics	Halley	Tempel 2
Tail structure (cont)		
	Numerous envelopes showing "closing umbrella" phenomena	
	Ion tail begins to form ∿1.5 AU pre-perihelion. Dust tail begins to form near perihelion	
	Maximum visual tail length ∿0.75 AU reached 5 to 6 weeks postperihelion	
Calculated		
Radius	2.5 km	1.5 km
Production rate, molecules sec^{-1}	7×10^{29} (peak) 4×10^{28} (at flyby)	7×10^{25} (at rendezvous) 1×10^{27} (peak)

A solar electric propulsion system must be operated nearly continuously between launch and a few days preceding the Halley flyby and then again from a few days after the Halley encounter until the rendezvous with Tempel 2. An ecliptic plane projection of the trajectory is shown in Figure 5-1. The Halley flyby imposes only a very modest performance penalty on the trajectory to Tempel 2.

A. HALLEY FLYBY

The spacecraft flies by Halley at 57 km s^{-1}. At such a very high speed, impacting dust grains might severely or fatally damage the rendezvous spacecraft. Thus the rendezvous spacecraft cannot come close to the nucleus and should be targeted to pass approximately 10^5 km

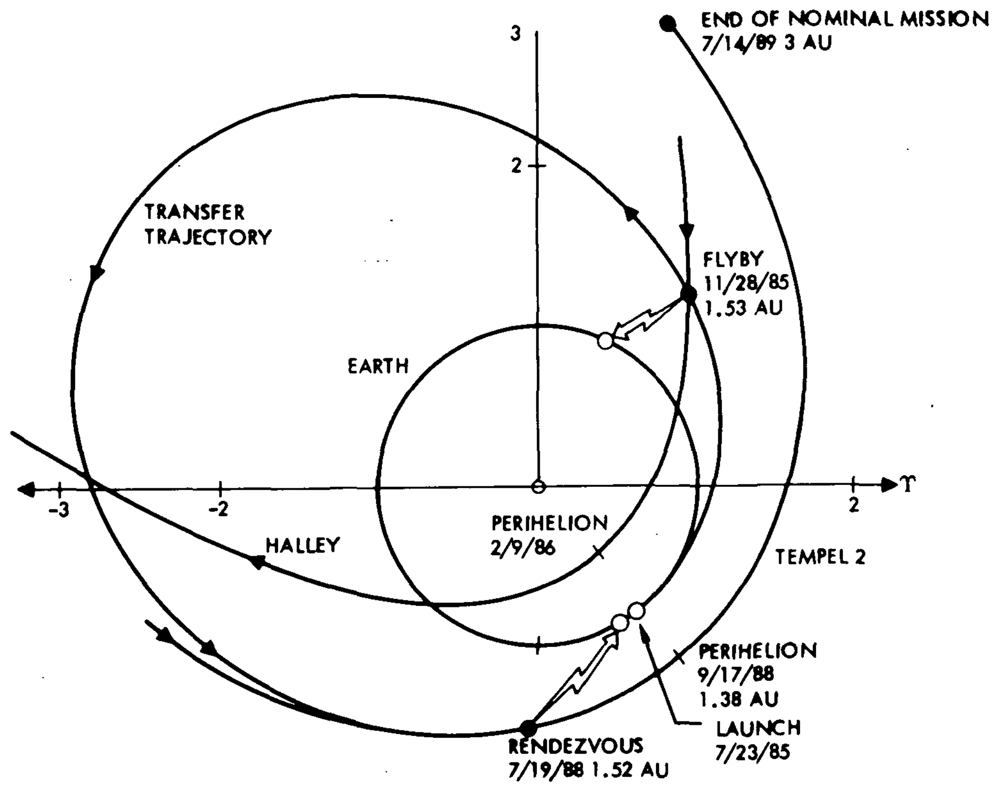

Figure 5-1. Heliocentric Trajectory (Ecliptic Plane Projection)

sunward of Halley to minimize the dust hazard and maximize the remote sensing of Halley. To obtain in situ data on conditions within the inner coma of Halley, a coma probe is required and should be released and targeted directly at the nucleus. The probe should include protective dust shielding to increase its probability of surviving to within $\leq$1000 km of the nucleus.

The scientific value of the mission would be enhanced still further if a second probe passed through Halley's tail at approximately the same time. Because it is not feasible for the rendezvous spacecraft to carry such a tail probe, it would have to be launched independently. The CSWG recommends that NASA continue to explore possibilities of international cooperation in the area of Halley probes.

B. TEMPEL 2 RENDEZVOUS

The CSWG recommends the following <u>adaptive</u> strategy for the rendezvous with Tempel 2:

(1) The spacecraft should arrive at Tempel 2 as long before perihelion as possible.

(2) It should make an exploratory pass as close to the nucleus as deemed safe (within about 100 km) soon after arrival and before the time of maximum cometary activity, which is predicted to occur about 20 days after perihelion passage.

(3) The spacecraft should observe the comet from a minimum safe distance (perhaps 1000-2000 km) during the phase of maximum activity.

(4) As postperihelion activity subsides, the spacecraft should make closer and closer passes of the nucleus to collect samples of cometary dust and make more detailed measurements of the coma and nucleus.

(5) As the comet settles into its quiescent state, the spacecraft should orbit the nucleus at a range of about 10 km, if possible, for a period of 100-150 days.

(6) The mission should end with an attempt at an experimental descent onto the nucleus.

Within these constraints, a mission strategy should be sought that allows an excursion antisunward of the nucleus to study tail phenomena.

The total rendezvous time required for the exploration of Tempel 2 is approximately one year.

SECTION VI

SCIENTIFIC INSTRUMENTATION

The CSWG has identified a set of candidate instruments that will fulfill the scientific objectives of the Halley flyby/Tempel 2 rendezvous mission. Examples of possible scientific payloads for the rendezvous spacecraft and the Halley coma probe are given in Tables 6-1 and 6-2. In many cases, only slight modifications to instruments that have flown on previous space missions are involved; others require special modifications or new developments. The CSWG is satisfied that development work is progressing at a satisfactory rate in all the necessary areas. Special attention should be and is being given to developing: (1) a means of operating mass spectrometers in dusty environments, (2) efficient mechanisms for collecting cometary dust for on-board analyses, (3) improved techniques for determining the composition of both collected dust samples and of the cometary nucleus, (4) designs of new imaging systems which meet the requirements of the rendezvous spacecraft and the probe, and (5) radar sounding instruments for studying the internal structure of the nucleus.

The CSWG also recommends the continuation of efforts to improve the models of the dust environments of Halley and Tempel 2 and of the effects of this dust on the spacecraft and its scientific instruments.

Table 6-1. Scientific Instruments for Rendezvous Spacecraft

Instrument	Mass Range, kg	Power, W	Date Rate, kb/s
Typical Payload			
Neutral mass spectrometer	8 to 10	14	1
Thermal ion mass spectrometer	4 to 6	2	0.1
Solar wind and electron analyzer	7 to 10	15	0.4
Magnetometer	4 to 5	3.5	0.2
Imaging system	25 to 30	22	115
Collected dust analyzer	25 to 30	20	1
Dust counter	2 to 5	10	0.01
Radiometer	5 to 7	5	0.1
X-ray or γ-ray spectrometer	10 to 12	13	0.01
Optical spectrometer	5 to 10	4	2
Radar altimeter[a]			
Accelerometer[a]			
Total	95 to 125	108.5	115 (max)
Other Instruments			
Radio sounder	13	25	16
Plasma wave analyzer	1 to 3	2	0.05

[a]Part of engineering subsystem.

Table 6-2. Representative Coma Probe Payload

Instrument	Mass, kg	Power, W	Maximum Data Rate, kb/s
Dust analyzer	8	10	3
Dust counter	1	1.5	0.1
Neutral mass spectrometer	7	8	2
Ion mass spectrometer	7.5	5	1.6
Electron and proton analyzer	5	5	1
Magnetometer	3.5	3.5	1
Plasma wave analyzer	3	3	1
Imaging system	5	7	2.5
Total	40	43	12.2

SECTION VII

BACKUP MISSIONS

The CSWG concluded that the baseline mission—a flyby of Comet Halley followed by a rendezvous with Comet Tempel 2—is the optimum mission available; no alternatives exist that are competitive with it either in scientific value or in cost effectiveness.

The most nearly acceptable alternative would be a Halley flyby and a Tempel 2 rendezvous achieved by separate launches. Fiscally responsible versions of such a scenario yield substantially inferior remote sensing of Halley and a loss of the capability to deliver a spacecraft close to its nucleus.

Considerable further study would be necessary to determine the best strategy and instrument complement for any alternative mission.

SECTION VIII

FOLLOW-ON MISSIONS

Because of the complexity of cometary phenomena and the diversity among comets, a single mission to one or two comets will not yield all the information needed to understand comets and their relationship to the rest of the universe. The CSWG believes that direct laboratory measurements on returned samples of cometary material are essential for answering some fundamental questions.

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